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Kroll

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[54] **TEMPERATURE AND CURRENT LIMITED ABLATION CATHETER**

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[51] **Int. Cl.**[7] **A61B 18/18**

[52] **U.S. Cl.** **606/41**; 606/29; 606/34; 607/101

[58] **Field of Search** 606/27–31, 41, 606/42, 45–50; 607/98–102

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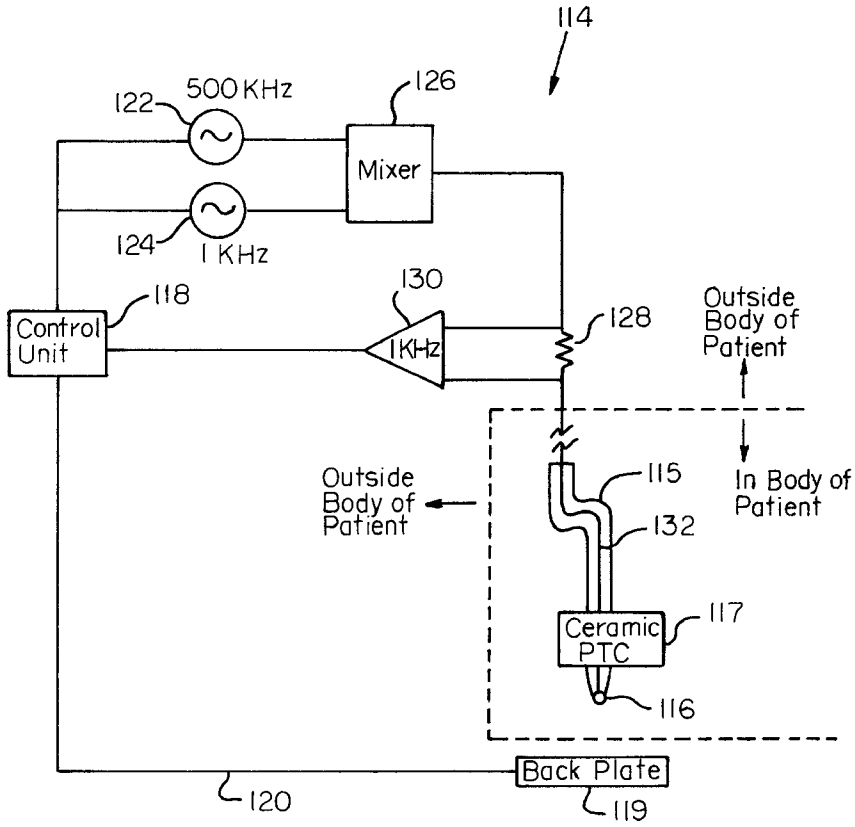
Attorney, Agent, or Firm—Scott R. Cox

[57] **ABSTRACT**

An ablation catheter of the present invention includes a means for limiting a current and temperature at a target tissue site. The ablation catheter includes a tip electrode at its distal end, and a positive temperature coefficient (PTC) device between the distal end and a proximal end of the catheter. Both the PTC device and electrode are electrically connected via a conductor extending within the catheter.

4 Claims, 5 Drawing Sheets



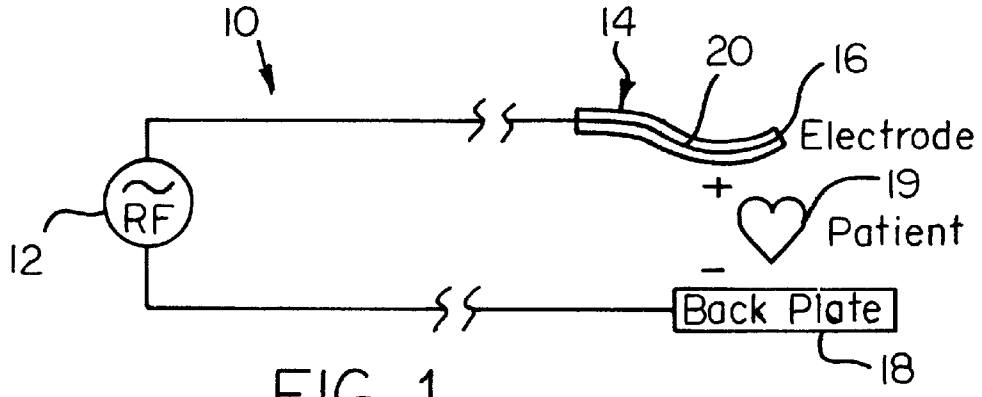


FIG. 1
(PRIOR ART)

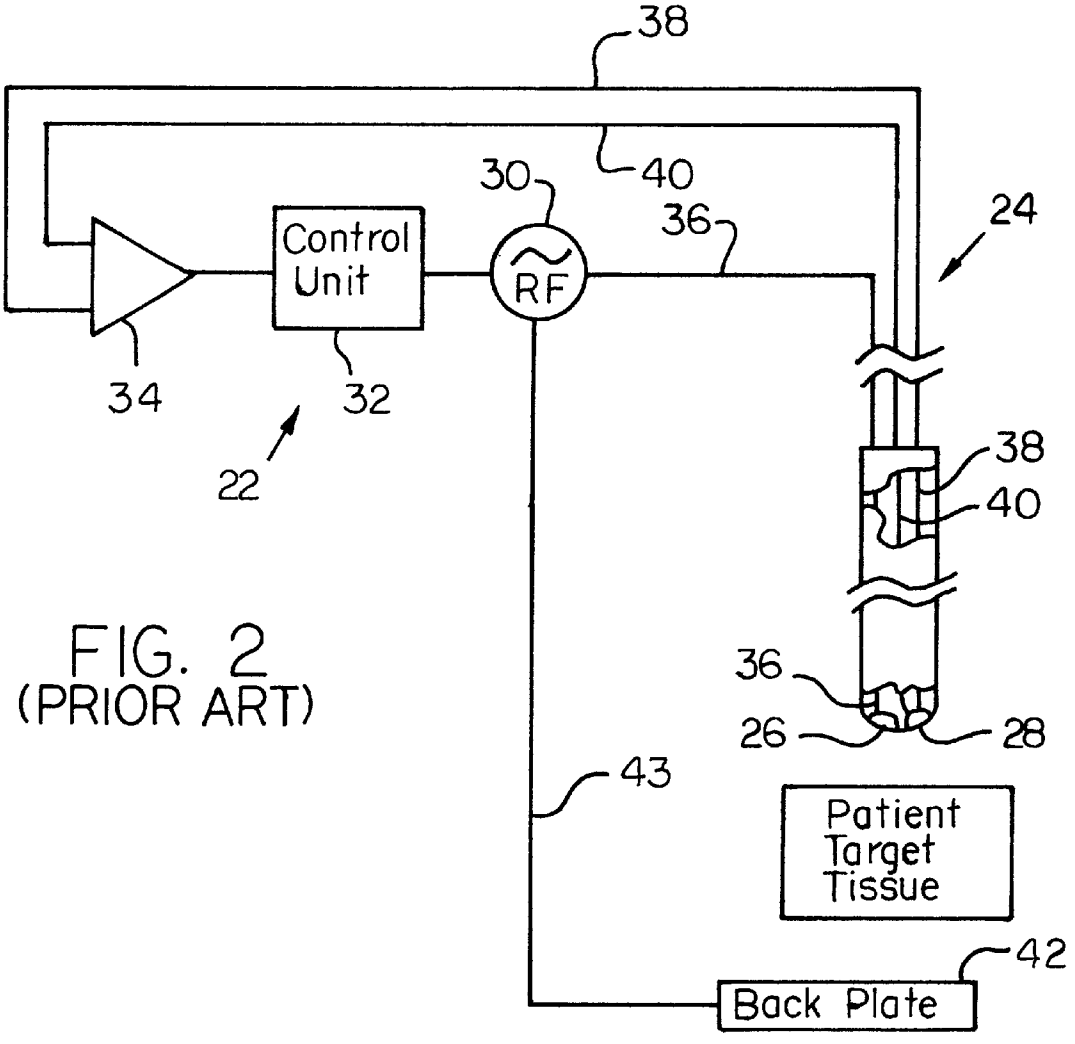


FIG. 2
(PRIOR ART)

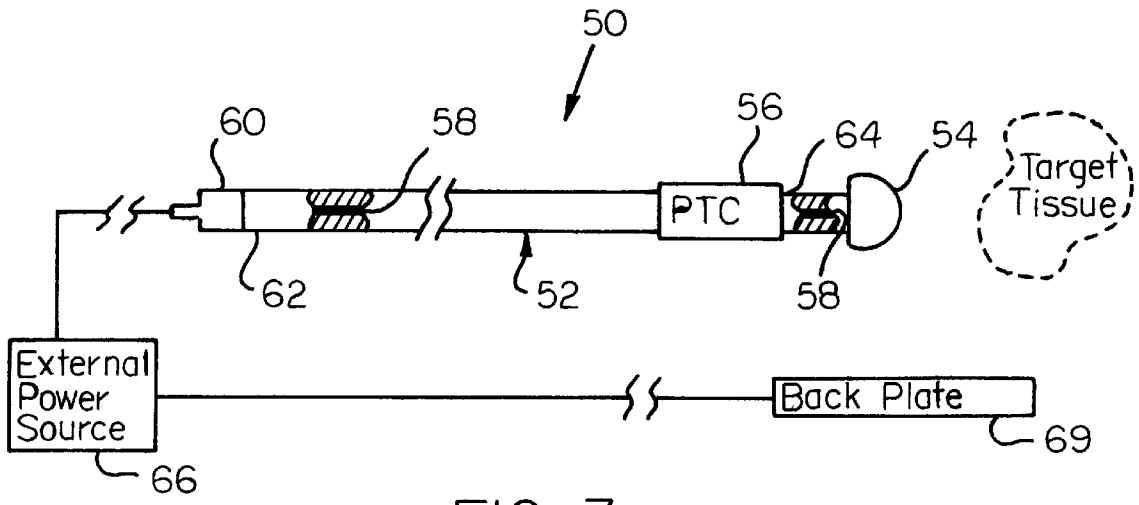

50
60
58
56
64
54
Target Tissue
PTC
62
52
58
External Power Source
66
Back Plate
69

FIG. 3

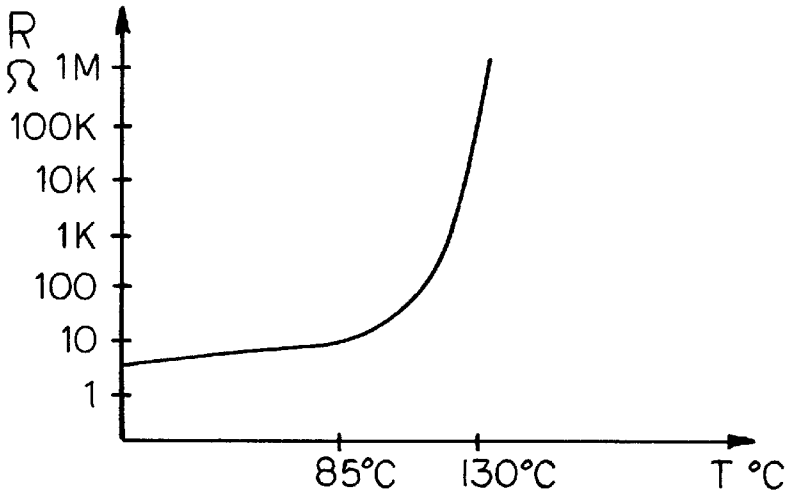

R
Ω
1M
100K
10K
1K
100
10
1
85°C
130°C
T °C

FIG. 4

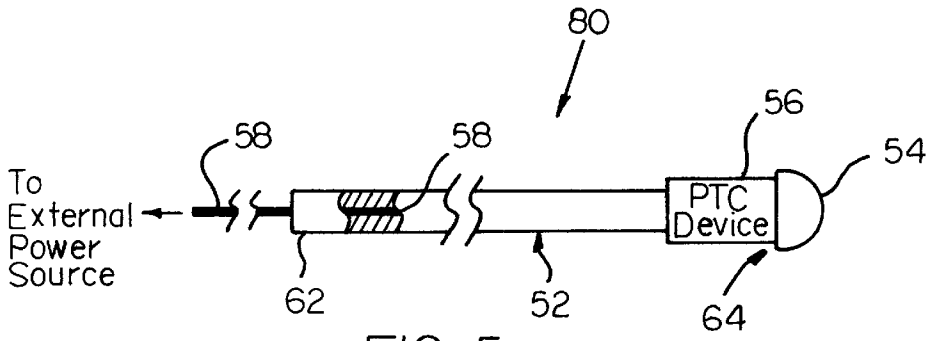

80
56
58
58
54
To
External
Power
Source
PTC
Device
62
52
64

FIG. 5

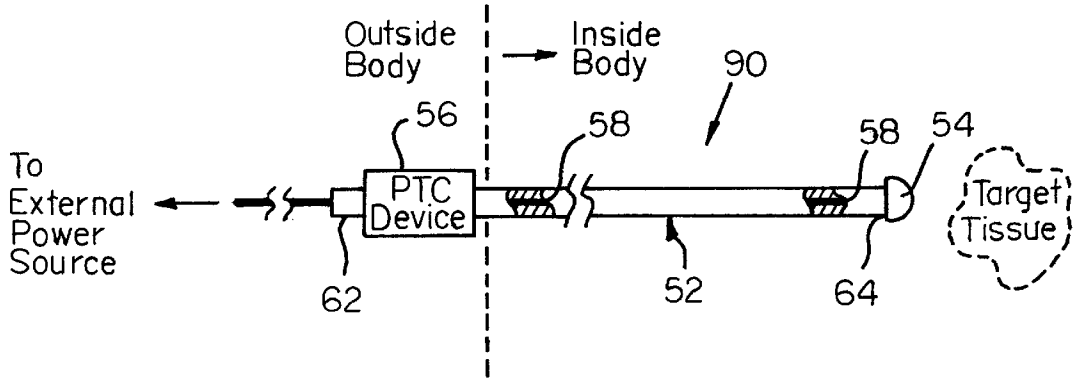

Outside
Body
Inside
Body
90
56
58
58
54
To
External
Power
Source
PTC
Device
Target
Tissue
62
52
64

FIG. 6

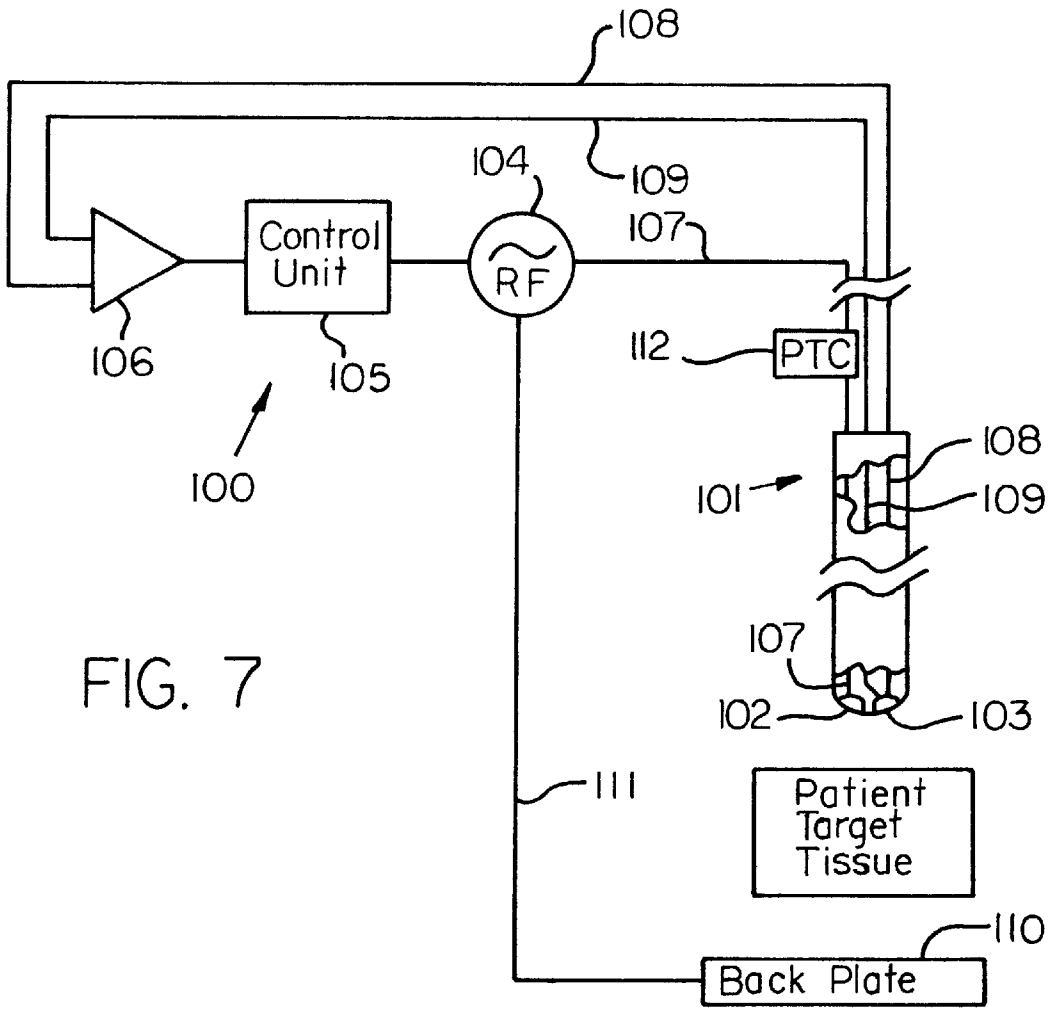

108
104
109
107
Control Unit
RF
106
105
112
PTC
100
101
108
109
107
102
103
111
Patient Target Tissue
110
Back Plate

FIG. 7

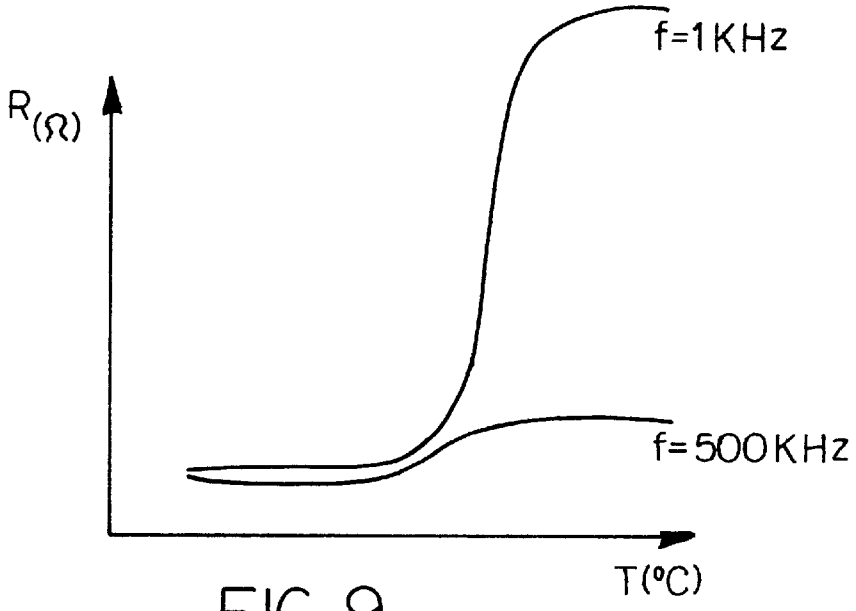

f=1KHz
R(Ω)
f=500KHz
T(°C)

FIG. 9

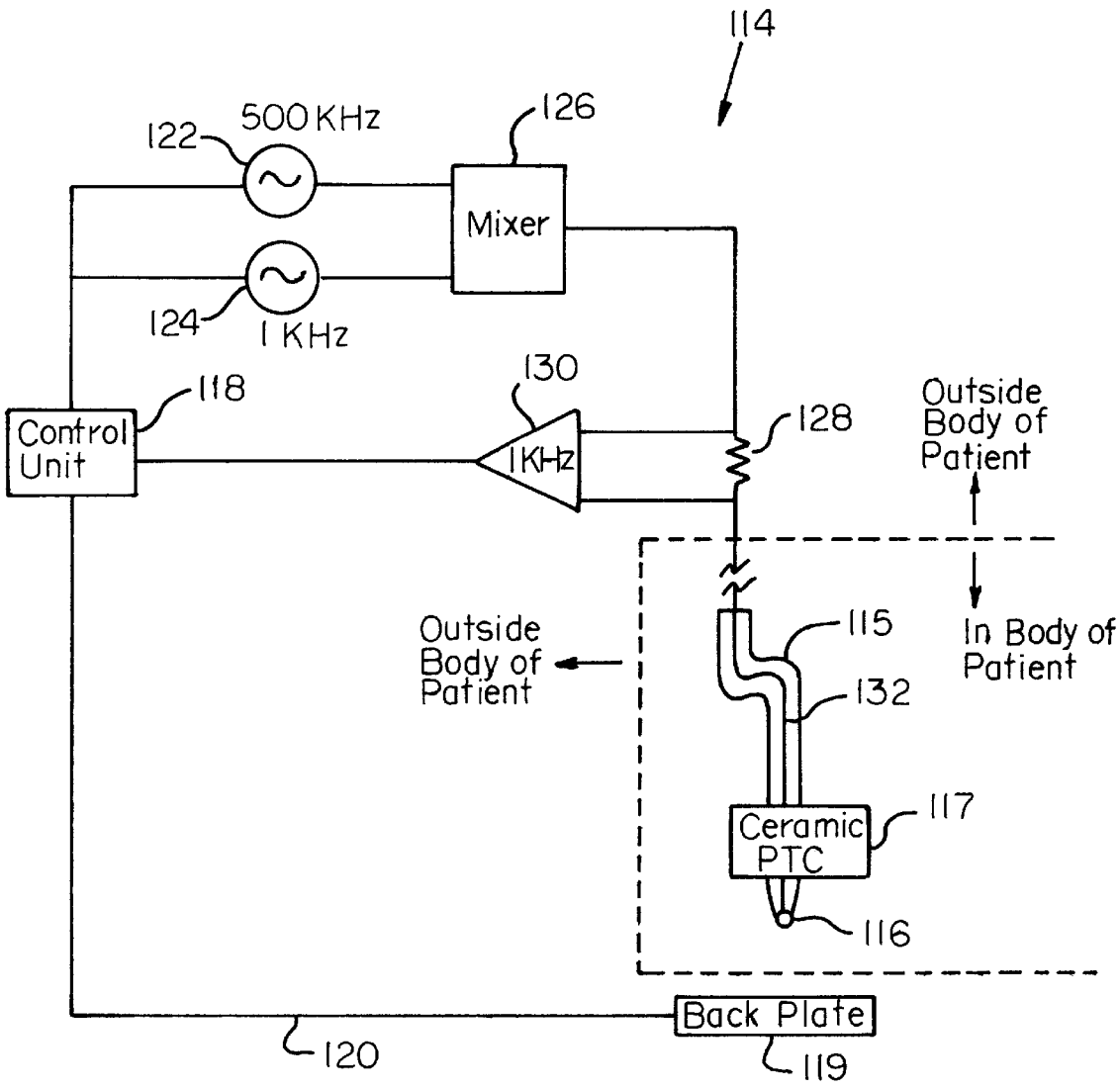

114
122
500 KHz
126
Mixer
124
1 KHz
130
118
Control Unit
1KHz
128
Outside Body of Patient
In Body of Patient
Outside Body of Patient
115
132
Ceramic PTC
117
116
Back Plate
120
119

FIG. 8

TEMPERATURE AND CURRENT LIMITED ABLATION CATHETER

FIELD OF THE INVENTION

The present invention relates to ablation catheters. In particular, the present invention relates to a temperature and current limited ablation catheter.

BACKGROUND OF THE INVENTION

Ablation catheters are well recognized and important tools for conveying an electrical stimulus to selected locations within the human body. Ablation catheters have been used for many years for the treatment of certain types of cardiac arrhythmia. For example, ablation catheters have been used to interrupt or modify existing conduction pathways associated with arrhythmias within the heart. Ablation procedures are also used for the treatment of atrial ventricular (AV) nodal reentrant tachycardia. Accepted treatments of this condition include ablation of the fast or slow AV nodal pathways. Known cardiac ablation procedures focus on the formation of lesions within the chambers of the heart at selected locations which will either prevent the passage of electrical signals associated with atrial premature contractions or prevent the formation of improper electrical pathways within the heart which can result in atrial arrhythmia.

Radio frequency (RF) catheter ablation has become increasingly popular for many symptomatic arrhythmias such as AV nodal reentrant tachycardia, AV reciprocating tachycardia, idiopathic ventricular tachycardia, and primary atrial tachycardias. Nath, S., et al., "Basic Aspects Of Radio Frequency Catheter Ablation," *J Cardiovasc Electrophysiol*, Vol. 5, pgs. 863–876, October 1994. RF ablation is also a common technique for treating disorders of the endometrium and other body tissues including the brain.

A typical RF ablation system in its most basic form comprises an RF generator which feeds current to a catheter containing a conductive tip electrode for contacting targeted tissue. The system is completed by a return path to the RF generator, provided through the patient and a large conductive plate, which is in contact with the patient's back.

The standard RF generator used in catheter ablation produces an unmodulated sine wave alternating current at frequencies of approximately 500 to 1000 kHz. The RF energy is typically delivered into the patient between the conductive tip electrode of the catheter and the large conductive plate in contact with the patient's back. During the delivery of the RF energy, alternating electrical current traverses from the conductive tip through the intervening tissue to the back plate. The passage of current through the tissue results in electromagnetic heating. Heating tissue to temperatures above 50° C. is required to cause irreversible myocardial tissue injury. However, heating tissue to temperatures above approximately 100° C. at the electrode/tissue interface can result in boiling of plasma and adherence of denatured plasma proteins to the ablation electrode. The formation of this coagulum on the catheter tip causes a rapid rise in electrical impedance and a fall in the thermal conductivity, resulting in loss of effective myocardial heating. Nath, S., et al., "Basic Aspects Of Radio Frequency Catheter Ablation," *J Cardiovasc Electrophysiol*, Vol. 5, pgs. 863–876, October 1994. Moreover, such extreme heating of the tissues can damage healthy tissue surrounding the targeted lesion.

Because of the dangers of overheating tissue with ablation catheters, systems for controlling the temperature at the ablation site are necessary. Such systems have been in use

for many years. Common ablation systems for controlling the temperature at the ablation site contain an electrode as well as a thermocouple or thermistor at the tip of the catheter. In these systems, a pair of wires from the thermocouple extend back through the body of the catheter to an amplifier in an electrical control portion of the system. An output from the amplifier, is indicative of the temperature of the heated tissue and is used by a control unit to control the duty cycle or power level of the RF generator. This arrangement permits regulating the amount of RF energy delivered to the tissue to control the temperature at the target tissue. An example of a system in which the duty cycle of the ablation catheter is controlled by a temperature sensor is disclosed in U.S. Pat. No. 5,122,137 entitled "Temperature Controlled RF Coagulation."

Known RF ablation systems that use temperature control mechanisms have numerous disadvantages. First, additional wires are required for the connection to the thermocouple. Each additional wire is a reliability and manufacturing problem when constructed in a long, thin catheter. Second, the transmission of a low voltage signal from the thermocouple to the amplifier, which is indicative of the temperature, must be transmitted accurately over a long distance in order to appropriately limit the temperature. Maintaining an accurate transmission is very difficult because the low voltage signals from the thermocouple are being transmitted by wires directly adjacent the wire used to provide the high voltage signal for ablating. The low voltage signals from the thermocouple are typically swamped by the high voltages and high frequencies used for the ablation, thereby causing temperature signals to be very noisy and less likely to give accurate temperature readings. Finally, in the event of an electronics fault, there is no mechanism in the known devices for current limiting or fusing capability to protect the patient and/or catheter.

SUMMARY OF THE INVENTION

An ablation catheter of the present invention includes a means for limiting the current and temperature at a target tissue site. The ablation catheter includes a tip electrode at its distal end, and a positive temperature coefficient (PTC) device between the distal end and a proximal end of the catheter. Both the PTC device and electrode are electrically connected via a conductor extending within the catheter.

The PTC device limits a current flowing to the electrode according to an exponential temperature and resistance relationship of the PTC device. Accordingly, when the temperature of the PTC device reaches a specified level, the PTC device becomes extremely resistive. This reaction effectively limits the current delivered to the target tissue and thereby ultimately limits the temperature of the target tissue by decreasing the amount of ablative RF energy directed to the target tissue.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic drawing of a basic known RF ablation catheter system.

FIG. **2** is a schematic drawing of a known temperature controlled RF ablation catheter system.

FIG. **3** is a schematic drawing of a temperature and current limited ablation catheter according to the present invention.

FIG. **4** is a graph illustrating a resistance and temperature performance relationship of a positive temperature coefficient (PTC) device of the present invention.

FIG. **5** is an alternative embodiment of a temperature and current limited ablation catheter according to the present invention.

FIG. **6** is an alternative embodiment of a temperature and current limited ablation catheter according to the present invention.

FIG. **7** is a further alternative embodiment of a temperature and current limited ablation catheter according to the present invention.

FIG. **8** is yet another alternative embodiment of an ablation catheter of the present invention using two frequencies.

FIG. **9** is a graph illustrating a resistance and temperature relationship of a ceramic PTC device at multiple frequencies.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention includes a temperature and current limited ablation catheter. As previously stated, ablation catheters are well recognized and important tools for conveying an electrical stimulus to selected locations within the human body. FIG. **1** illustrates a schematic drawing of a known basic RF ablation catheter system **10**. System **10** includes an RF signal generator **12**, a catheter **14**, a tip electrode **16** and a backplate **18**. An electrical conductor **20** within catheter **14** extends between and electrically connects electrode **16** to RF generator **12**. In operation, RF generator **12** feeds a current to catheter **14** via conductor **20**. During the delivery of RF energy, alternating electrical current traverses from tip electrode **16** through the intervening tissue **19** of the patient to backplate **18**. The passage of current through the tissue results in resistive (joule) heating. When using an ablation system, the targeted tissue must be heated to temperatures above approximately 50° C. for effective ablation. However, temperatures at and above approximately 100° C. at the electrode/tissue interface can result in boiling of plasma and adherence of denatured plasma proteins to the ablation electrode. The formation of the coagulum on the catheter tip causes a rapid rise in electrical impedance and a fall in the thermal conductivity resulting in loss of effective myocardial heating. Because of the dangers of overheating tissue with ablation catheters, systems for controlling the temperature at the ablation site are necessary and such systems have been in use for many years.

FIG. **2** illustrates a known ablation system **22** for controlling the temperature at an ablation site. Ablation system **22** contains a catheter **24** having a tip electrode **26** and a thermocouple **28** connected to the distal end of catheter **24**. System **22** also includes an RF generator **30**, a control unit **32** and an amplifier **34**. Electrode **26** is connected to RF generator **30** through a conductor **36**. Thermocouple **28** is connected to RF generator **30** through control unit **32** and amplifier **34** via a pair of conductors **38**, **40**. A backplate **42** is also connected to RF generator **30** via conductor **43** to provide a return path for the current. In system **22**, the output from amplifier **34** is indicative of the temperature sensed by thermocouple **28** and is used by control unit **32** to control the duty cycle or power level of RF generator **30**. Despite this temperature control arrangement, this known ablation system may fail to optimally regulate temperatures at the target tissue due to the possibility of: (1) reliability/manufacturing problems; (2) inaccurate temperature signal transmission; and (3) a lack of other limits on the RF energy provided to the tissue.

The present invention provides a radio frequency ablation catheter using a positive temperature coefficient (PTC) device in series with an electrode to provide a current limited and temperature limited device. FIG. **3** is a schematic drawing of a temperature and current limited ablation catheter **50** according to one preferred embodiment of the present invention. Catheter **50** includes a flexible body **52**, a tip electrode **54** and a positive temperature coefficient (PTC) device **56**, as well as a conductor **58**, and a connector **60**.

Flexible body **52** extends from the proximal end **62** to the distal end **64** of catheter **50**. The composition of flexible body **52** is known to those skilled in the art. Catheter body **52** should be sufficiently pliable to permit the catheter to be advanced through the vascular system of the patient, for example, into the heart and ultimately into a pulmonary vein. In one embodiment of the present invention, the distal portion of catheter body **52** may be more pliable and less stiff than the remaining proximal portions of the catheter to assist the catheter in the advancement throughout the body. However, the pliability of catheter body **52** may also be consistent throughout its entire length. Additionally, catheter body **52** may be reinforced, for example, by use of a reinforcing braid or other such suitable strand material having high temporal strength.

Tip electrode **54** is connected to distal end **64** of catheter **50**. Tip electrode **54** is used to deliver current from an external power source **66** to the tissue to be ablated. Tip electrode **54** is a standard tip electrode known to those skilled in the art. The single conductor **58** extends from proximal end **62** to distal end **64** within flexible body **52**. Conductor **58** conducts the current from external power source **66** to tip electrode **54**. The current loop is completed through the patient and back plate **69**. Connector **60** is optionally provided at proximal end **62** to ease connection between conductor **58** and external power source **66**. In the preferred embodiment of the present invention, external power source **66** is an RF generator, and reference will be made to an RF generator from hereout.

RF generators are known in the art. Examples include the EPT-1000™ from E.P. Technologies, the EP-Shuttle™ manufactured by Stockert GmbH and the RFG-30™ from Radionics, Inc. These devices typically produce radio frequency signals in the 500–1000 kHz range with power levels in the 0–100 watt range. These devices also have minimum and maximum impedance cut off ranges. For example, the EPT-1000™ has a pre-set 300 Ω maximum impedance cut off and a pre-set 50 Ω minimum impedance cut off. The maximum impedance cut off is to alert the operator, for example, that the catheter is broken and therefore there is an open circuit. The minimum impedance cut off is to alert the operator, for example, that there is a short circuit somewhere. The EP-Shuttle™ by Stockert has operator selectable maximum and minimum impedance cut off ranges. The maximum impedance is selectable between 50 and 300 Ω while the minimum impedance is selectable between 20 and 200 Ω. The EP-Shuttle™ also has an operator selectable maximum change in impedance (Δ) setting, selectable between 1–999 Ω.

In the present invention, positive temperature coefficient (PTC) device **56** is connected in series between proximal end **62** of catheter body **52** and tip electrode **54**. PTC device **56** acts as an intrinsic fail-safe current limiting device. In the embodiment illustrated in FIG. **3**, PTC device **56** is positioned adjacent tip electrode **54** but is not in thermal contact with electrode **54**. In the embodiment illustrated, PTC device **56** is positioned approximately 5 cm from distal end **64**. This is done for ease of construction. It should be noted, however, that PTC device **56** could be positioned anywhere between power source **66** and tip electrode **54** as will be described in greater detail below.

As previously stated, PTC devices are known as positive temperature coefficient devices. A known technique for making a PTC device is to use a very thermally expansive polymer that is blended with conductive materials. In this case, at low operating temperatures, the device may have very low resistance, typically less than 1 ohm. When a high current flows through the device, the device will begin to heat from joule heating. The increased temperature will cause an expansion of the polymer and change it to an amorphous state. This change separates the conductive paths within the polymer and causes a dramatic increase in the device resistance. The device resistance can change by a factor of 10,000,000 to 1 before the device fails. This dramatic response is illustrated by the graph in FIG. **4**, which illustrates a sample resistance and temperature performance relationship of a positive temperature coefficient device.

It should be understood that the resistance/temperature relationship shown in FIG. **4** is only shown as an example of one configuration of a PTC device. This relationship may be altered and tailored to the user's specifications depending upon the size, shape, and type of PTC device used. For example, the PTC device can be designed to have the rapid rise in resistance occur at approximately 130° C. as in FIG. **3**, or to have it occur at greater or lesser temperatures. This gives great flexibility in designing current and temperature limited ablation systems.

One known PTC device is made by the Raychem Corporation of California under the brand name PolySwitch® Rxe. This Raychem model is not reactive (having no internal capacitance), permitting the polymer PTC device to function well at higher radio frequencies typically used for ablation. However, another known PTC device is made by the Siemens Matsushita Component Company, which has a ceramic construction well suited for limiting currents at moderate temperatures. Other PTC devices also may be used without departing from the spirit or scope of the present invention.

In operation, RF current is delivered from RF generator **66** through conductor **58** of catheter **50** to tip electrode **54**. With tip electrode **54** in contact with the target tissue within the heart (or other portion of the vascular system), the RF power is delivered to the target tissue with the system circuit being completed through conductive backplate **69**. RF power is supplied through tip electrode **54** to cause the target tissue to heat to a temperature of between 50° C. and 100° C. Heating the target tissue into the desired ablating range requires the application of substantial current through PTC device **56** to tip electrode **54**. As the required current level increases, PTC device **56** begins to change to an amorphous state, thus increasing its resistance. It must be remembered that the resistance/temperature relationship depends upon the size, shape and type of PTC device selected. Using the relationship illustrated in FIG. **3**, at current levels required to achieve ablation temperatures above 100° C., an ultra-high resistance is exhibited by PTC device **56**. During the period of time in which PTC device **56** is changing from low resistance to high resistance, the current to electrode **54** is being reduced to effectively limit the current to electrode **54**. Once the resistance of PTC device **56** is high enough, the maximum impedance cut off, or the maximum change in impedance cut off for the EP-Shuttle™, will be triggered causing RF generator **66** to stop outputting the RF signal. Thus, the current is limited. This also limits the temperature at the target tissue. By properly selecting the PTC device characteristics, the temperature at the target tissue may be maintained below 100° C. RF generator **66**, will stay off until PTC device **56** has cooled down such that its resistance drops into an acceptable range. Cooling is provided by the rapidly flowing blood in the vascular system. Maintaining the temperature below 100° C. by using PTC device **56** prevents the boiling of plasma and the adherence of denatured coagulum to tip electrode **54** which would otherwise inhibit effective ablation.

Catheter **50** of the present invention provides a simple, elegant solution with numerous advantages. First, the use of PTC device **56** allows temperature limiting or regulation of ablation catheter **50** at tip electrode **54** by the use of only a single conductor **58** as opposed to a common three wire configuration that extends through prior art systems such as that shown in FIG. **2** to support a thermocouple. Moreover, since PTC device **56** need not be placed directly adjacent to tip electrode **54**, the distal end of the catheter can be of a smaller design or of a design having different configurations not limited by the presence of a thermocouple. As previously stated, the particular tissue temperature at which PTC device **56** increases its resistance exponentially can be selected based upon the type and amount of power used so that a predetermined temperature range can be identified at which PTC device **56** limits the current and limits the temperature for ablation.

In addition to eliminating or reducing the extra number of wires that would be necessary to support a thermocouple-based temperature limiting system, catheter **50** of the present invention using PTC device **56** also provides a fusing-type capability for catheter **50** by virtue of its current limiting. Because of the current limiting capacity, a patient and/or catheter **50** is protected in the event of an electronics fault in the control unit or external power source which might otherwise cause the current to pass, or increase without constraint. Utilizing a single conductor wire in conjunction with a PTC device also eliminates the necessity for a feedback loop for monitoring and gauging the accuracy of a temperature signal from a thermocouple. Once the PTC device is selected for the desired predetermined temperature range at which it will limit the current, then a feedback loop for monitoring the temperature of the tip electrode is no longer necessary.

In one alternative embodiment of the present invention, PTC device **56** is insulated from the ambient conditions (e.g., surrounding vasculature and blood flow). In this embodiment, when PTC device **56** heats up from an over-current situation it does not cool down. This response results in a permanent/effective shut down of ablating the target tissue for two reasons. First, because of the high impedance of PTC device **56**, RF generator **66** would shut down. Second, even if RF generator **66** did not have a maximum impedance cut off feature, the current passing through tip electrode **54** would be limited as to no longer effectively ablate the tissue. In this embodiment, PTC device **56** acts as a fail-safe feature thereby protecting catheter **50** and the target tissue while alerting the operator to investigate the ablation shut down.

In another embodiment of the present invention, a catheter **80** includes substantially the same features and structures as catheter **50** except that PTC device **56** is in mechanical and/or thermal contact with tip electrode **54**. Thermal contact can be established by direct physical contact as shown in FIG. **5** or by other means known to those skilled in the art for providing thermal connectivity and conductivity between two devices such as PTC device **56** and tip electrode **54**. By establishing thermal contact between PTC device **56** and tip electrode **54**, catheter **80** has enhanced temperature limiting/shut off features in addition to the current limiting features provided by PTC device **56**.

Accordingly, in this embodiment, PTC device **56** is no longer a pure current sensing limiter.

In operation, catheter **80** is placed within the vascular system and tip electrode **54** is arranged for ablating the target tissue. By virtue of its positioning in physical contact with tip electrode **54**, PTC device **56** is in contact with rapidly flowing blood through the vascular system. The blood flowing by PTC device **56** will act as heat sink removing some of the heat generated by PTC device **56**. This cooling effect allows PTC device **56** to tolerate a slightly higher level of current before exhibiting a very high resistance than would be possible if PTC device **56** were not being cooled. Moreover, since the surrounding blood effectively cools PTC device **56**, PTC device **56** will not stay in a very high resistance state permanently after a current limit condition has been reached. Once catheter **80** is properly positioned within the vascular system, RF power is delivered to tip electrode **54** from the external power source. With tip electrode **54** in contact with the target tissue, the RF power is delivered to the target tissue with the system circuit being completed through backplate **69**. As the temperature of the target tissue rises, so too does the temperature of PTC device **56** because it is in thermal contact with tip electrode **54**. The target tissue will continue to be ablated until the temperature at the electrode/tissue junction rises to a level which causes PTC device **56** to change into a higher resistance state. Assuming that RF generator **66** is programmed to allow a moderate resistance change, the amount of current to tip electrode **54** will be automatically regulated to keep the temperature at the electrode/tip junction at an optimal level.

In another embodiment of the present invention, which is illustrated in FIG. **6**, catheter **90** is provided which has substantially the same features and attributes as catheter **50** of the present invention, except that catheter **90** includes PTC device **56** at proximal end **62** of catheter so that the PTC device remains outside of the body of the patient during an ablation procedure.

Operating catheter **90** with this arrangement allows PTC device **56** to operate as a pure current limiter with no temperature sensing characteristics. In addition, since PTC device **56** is not at the distal end of catheter **90**, construction of catheter **90** is greatly simplified and permits distal end **64** of catheter **90** to be formed with a smaller diameter tip which is useful for insertion into small regions of the vascular system. Of course, the PTC device is still electrically connected to the single conductor **58**, although being located at proximal end **62** of catheter body **52**.

FIG. **7** illustrates a further alternative embodiment of the present invention. In this embodiment, an ablation system **100** is provided. Ablation system **100** contains a catheter **101** having a tip electrode **102** and a thermocouple **103** connected to the distal end of catheter **101**. System **100** also includes an RF generator **104**, a control unit **105** and an amplifier **106**. Electrode **102** is connected to RF generator **104** through a single conductor **107**. Thermocouple **103** is connected to RF generator **104** through control unit **105** and amplifier **106** via a pair of conductors **108**, **109**. A backplate **110** is also connected to RF generator **104** via conductor **111** to provide a return path for the current. A PTC device **112** is electrically connected adjacent tip electrode **102** via conductor **107**. It should be noted that PTC device **112** can be located remotely from tip electrode **102**, similar to the embodiment of catheter **90** (see FIG. **6**) or in direct thermal contact with tip electrode **102**, similar to the embodiment of catheter **80** (see FIG. **5**). In this embodiment, temperature can be precisely monitored by combining the standard thermocouple temperaturelimiting arrangement while still providing fail-safe current and temperature shutdown limiting characteristics by use of the PTC device **112**. This embodiment maximizes the temperature regulating characteristics of the ablation catheter.

FIG. **8** illustrates a further alternative embodiment a catheter ablation system **114** according to the present invention in which two frequencies are used for ablation. Ablation system **114** includes a catheter **115**, tip electrode **116**, a ceramic PTC device **117**, a control unit **118** and a conductive backplate **119** connected via conductor **120**. System **114** further includes a 500 kHz RF signal generator **122**, 1 kHz signal generator **124**, a frequency mixer **126**, as well as a current sampling resistor **128** and frequency selective amplifier **130** tuned to 1 kHz. Ceramic PTC device **117** and tip electrode **116** are electrically connected via conductor **132** and are embodied in a catheter structure in accordance with the other embodiments of the present invention shown in FIGS. **3–7**.

As shown in FIG. **8**, system **114** uses two frequencies, namely 500 kHz and 1 kHz mixed via mixer **126** and delivered through current sampling resistor **128**, ceramic PTC device **117** and tip electrode **116**. The voltage drop across the sampling resistor **128** is amplified by frequency selective amplifier **130** which is tuned to 1 kHz. This amplification produces a signal flowing through conductor **132** that is indicative of the current flow at the low frequencies. In this system, if the temperature rises at ceramic PTC device **117**, then its impedance at low frequencies goes up dramatically. This relationship results in a decreased current flowing to tip electrode **116** with the output from amplifier **130** decreasing as a result of this sensed impedance change causing the control unit to reduce the 500 kHz output. This approach allows the precise monitoring of temperature along with the use of an intrinsic current and temperature limiting mechanism, all accomplished with the single wire conductor **132** which simplifies the catheter construction.

Catheter ablation system **114**, as shown in FIG. **8**, takes advantage of the unique properties of ceramic PTC devices which are very capacitive. The resistance of ceramic PTC devices increases very little in response to temperature changes when the ceramic PTC devices are run at high frequencies. This behavior results from the capacitive coupling across the grain boundaries in the ceramic composition of the PTC devices. This relationship is shown in FIG. **9**, which is a graph illustrating a resistance and temperature relationship of a ceramic PTC device operating at frequencies of 1 kHz and 500 kHz. As can be seen, in the low frequency range a dramatic increase in resistance occurs as temperature increases while at higher frequency range, very little increase in resistance occurs with the increase in temperature.

Yet another use of the present invention is linear lesion ablation catheters. Such catheters are very long which results in a high current density at the ends of the catheter thereby generating hot spots of excessive temperature. By using a PTC device of the present invention, current could be limited at the hot spots at the ends of the long catheter by converting the ends of the linear lesion catheters to small ring tip electrodes in combination with the PTC approach. A variant on this design would include using multiple PTC devices on each end of the long catheter.

An ablation catheter of the present invention incorporating a positive temperature coefficient conductor provides numerous advantages in radio frequency ablation. The PTC device provides a built in fail-safe current limiter to avoid over-ablating the target tissue thereby protecting the patient,

while insuring effective ablation with the catheter by preventing coagulation adherence to the catheter electrode tip and damage to the catheter and patient from overheating. Use of the PTC device to limit current and/or temperature at an ablation site within a vascular system greatly simplifies the task of temperature regulation which was previously provided by thermocouple-type systems.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

What is claimed is:

1. A radio frequency ablation system comprising:

an elongate flexible catheter including an electrical conductor having a proximal end and a distal end;

an electrode electrically connected to the distal end of the conductor;

a ceramic-type positive temperature coefficient (PTC) device electrically connected between the proximal end of the conductor and the electrode,

a control unit;

a frequency mixer;

a low frequency generator and a high frequency generator connected in parallel to and extending between the control unit and the frequency mixer;

a resistive component electrically connected between the frequency mixer and the ceramic-type PTC device;

a frequency selective amplifier having an output connected to the resistive component and an inlet connected to the control unit; and

a conductive plate electrically connected to the control unit for contacting a patient.

2. The ablation system as in claim **1**, wherein the PTC device is adjacent the electrode.

3. The ablation system as in claim **1**, wherein the conductor comprises a single conductor wire.

4. The ablation system as in claim **1**, wherein the PTC device is a ceramic-type PTC device.

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